Improving the precision of sea level data from satellite altimetry with high-frequency and regional Sea State Bias corrections

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Spoiler for Sea State Bias lovers

1) If you want to decrease the high-frequency noise of LRM altimetry by ~15%, apply the Sea State Bias model on 20-Hz data (alternative to „Zaron correction“, but focused on 20-Hz, not 1-Hz)

2) Going regional: a simple regional parametric sea state bias model is better than a global non-parametric one. Further improvements in precision (~30%)

3) Is this the final word? No, best strategy is: first eliminating intra-1Hz correlations between retracked parameter (different for each retracker), then re-estimate the SSB model at 1-Hz

4) Meanwhile, this is a solution that can be immediately applied to improve the precision

Theoretical Background

The Sea State Bias is currently computed empirically. Any error in altimetry data with some dependence on sea state (wind, backscatter coefficient, significant wave height, wave period, …) will go into this correction. Any SSB correction is computed and provided at 1-Hz rate.

SSB is considered „the largest source of uncertainty linked with the altimetric signal" (Pires et al., 2016).

„numerical", high-frequency source

„The inherent correlation [between range and wave height estimation in the retracking] has the same effect as the so-called sea state bias" (Sandwell and Smith, 2005)

Electromagnetic Bias

„physical" (low frequency?) source

Skewness Bias

„Tracker Bias" is actually „Retracker-related noise", as called by Zaron and Decarvalho

Motivation

- Strong interest of the community (SWOT, coastal oceanographers, Delay-Doppler altimetry) to work with high-frequency (HF) data, but corrections are provided at 1-Hz (Cipollini et al., 2017; Birol and Delebecque, 2014)

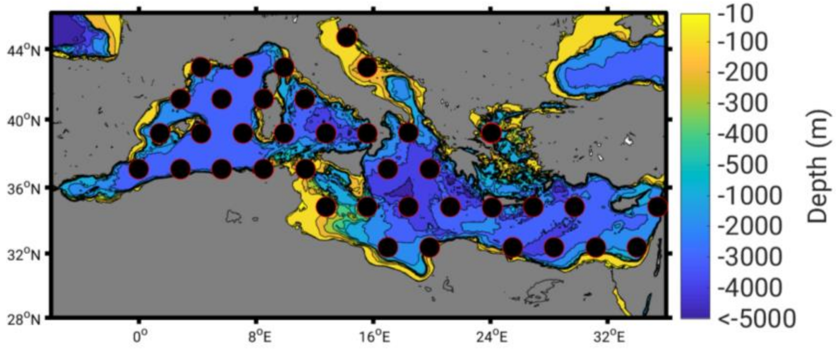
- A lot of new retrackers have been proposed, often without a specific Sea State Bias model. Do we need an SSB model for each retracker?

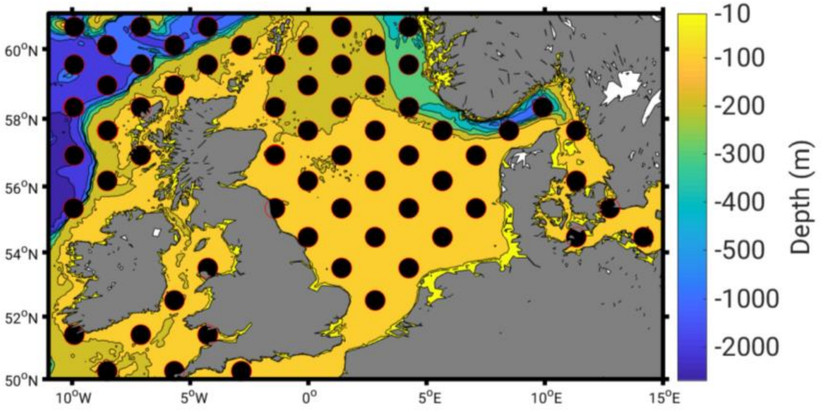
- Focus on regional sea level estimation (ESA‘s Sea Level Climate Change Initiative Bridging Phase). Region-dependent residual errors, prevalence of certain wind-wave conditions -> is a regional approach to correct for SSB desirable?

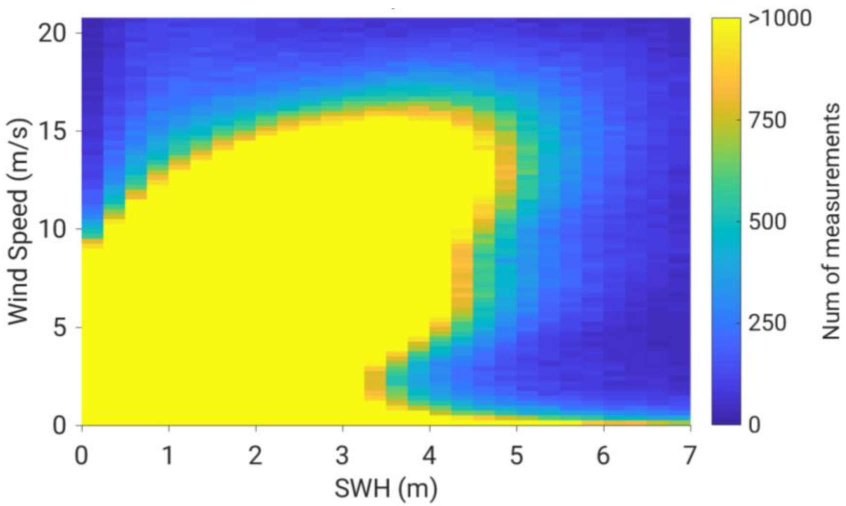
AIM: Can a high-rate and regional approaches to Sea State Bias application improve the precision of altimetry data?

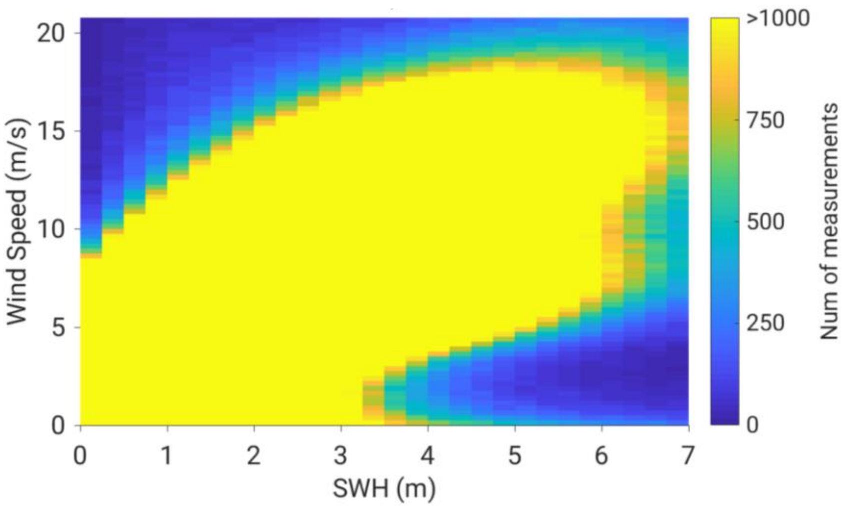
Area of study

Different bathymetry, different wind/wave climate









Methodology: models compared in this study

DATASET: ALES and MLE4 (called „SGDR“ in this study) in Jason-1, no coastal data (>20 km)

1) 1-Hz SSB: original correction provided in the GDR (Tran et al., 2010). Kernel smoothing to solve large system of observation equations (nonparametric method)

2) 20-Hz SSB: same model, correction applied at high-rate using wind speed and SWH data from the two retrackers

3) Reg SSB: parametric model derived for each retracker in each region and applied at HF

Methodology: regional model estimation

- The answer to our scientific question is independent of the way we model the SSB

- Therefore we use a simple modelling approach: Modelling the crossover differences (Sea Level Anomalies not corrected for SSB) with Fu&Glazman model following Gaspar et al. (1994)

- System of equation (one for each crossover) is solved in a least square sense for parameter determination:

$$SSB_{SGDR,Med} = -0.058 \times SWH \left(g \frac{SWH}{U_{10}^2} \right)^{0.00}$$

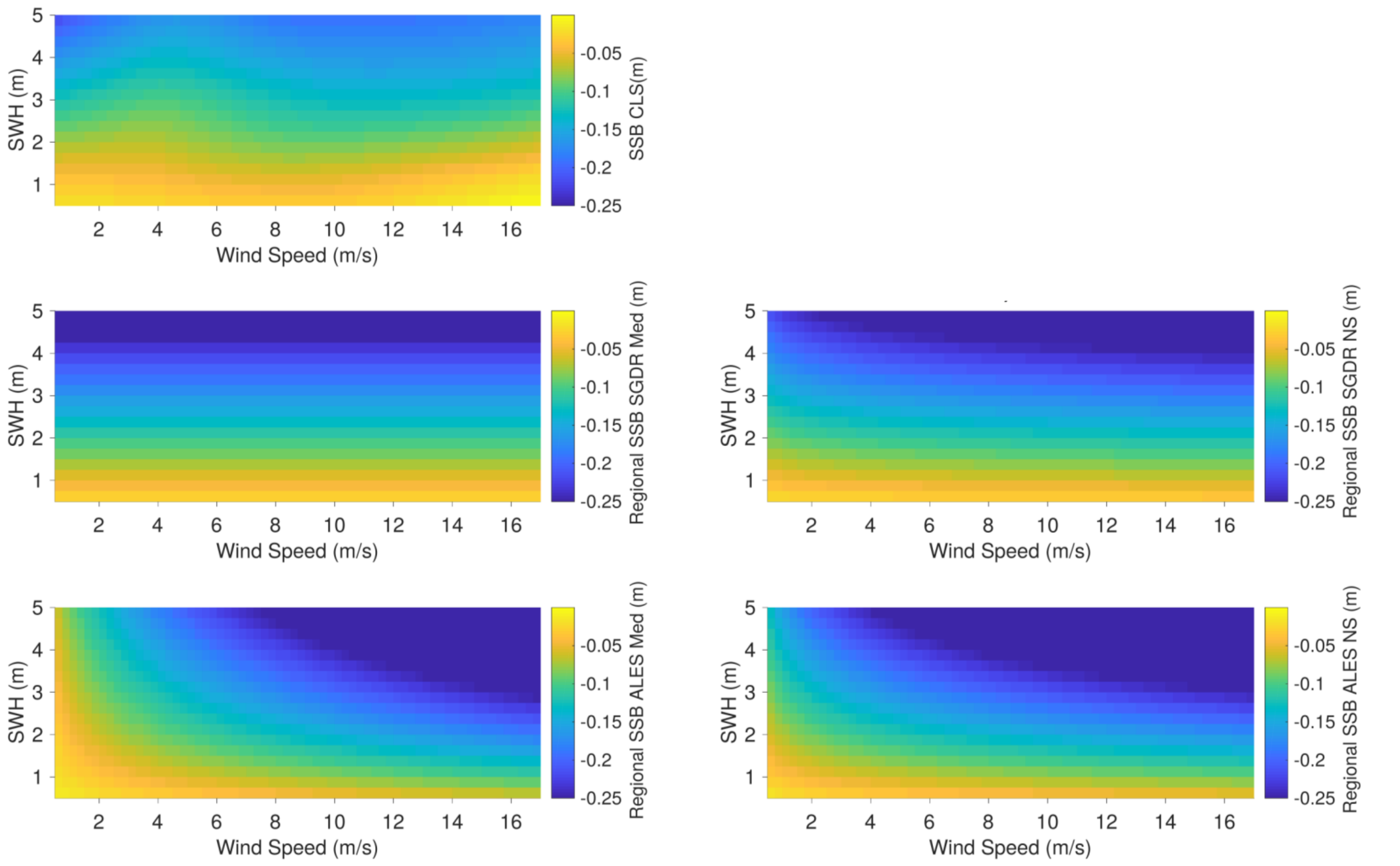
$$SSB_{SGDR,NS} = -0.058 \times SWH \left(g \frac{SWH}{U_{10}^2} \right)^{0.05}$$

$$SSB_{ALES,Med} = -0.050 \times SWH \left(g \frac{SWH}{U_{10}^2} \right)^{0.25}$$

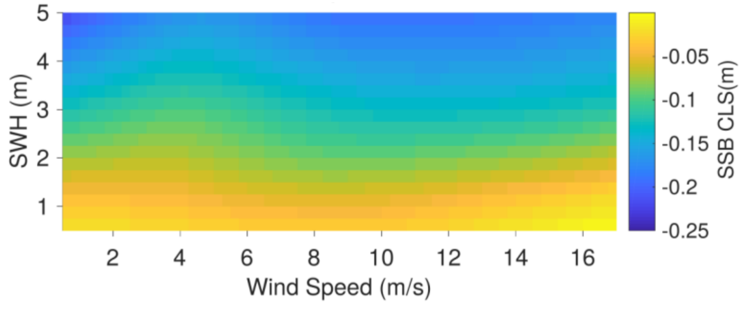
$$SSB_{ALES,NS} = -0.061 \times SWH \left(g \frac{SWH}{U_{10}^2} \right)^{0.15}$$

$$SSB = \hat{\alpha} SWH \left(g \frac{SWH}{U_{10}^2} \right)^{-\hat{d}}$$

Comparison of regional SSB models

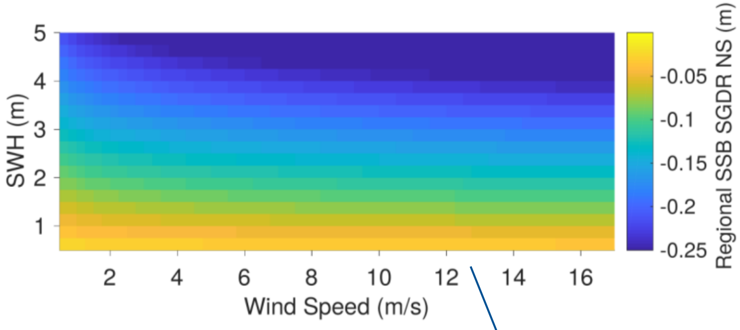


Comparison of regional SSB models



Original global SSB model, MLE4 retracker

Strong differences global vs regional: in particular higher sensitivity to SWH

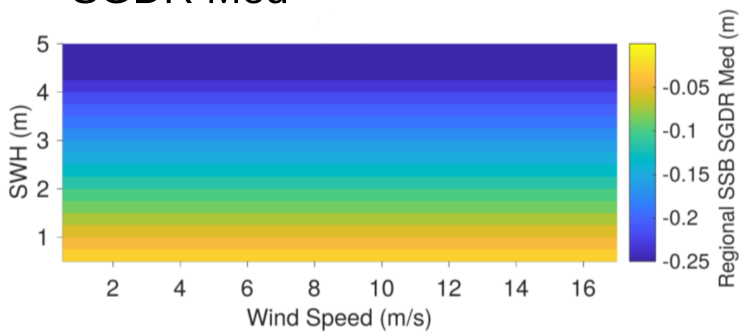


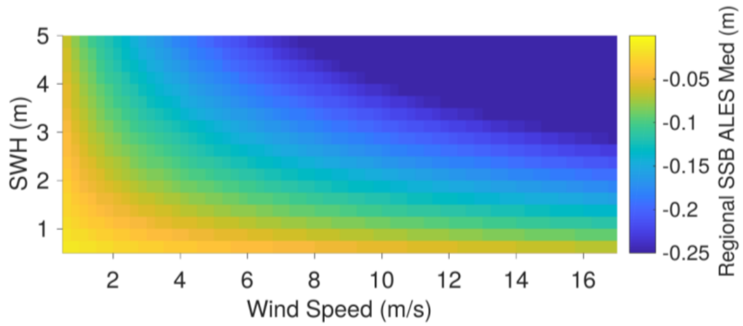
Same MLE4 retracker, regional North Sea model

Comparison of regional SSB

Difference between retrackers particularly evident for the contribution of wind (backscatter coefficient)-related effects

SGDR Med



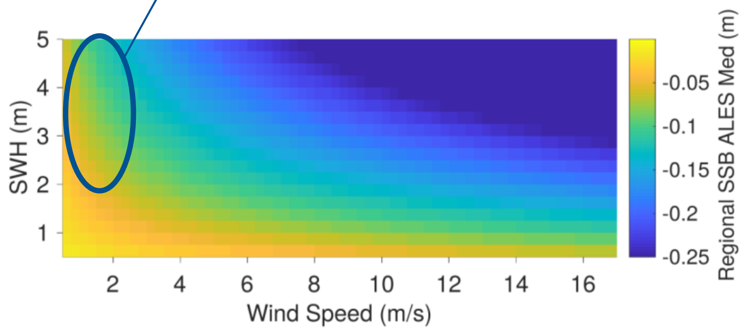


ALES Med

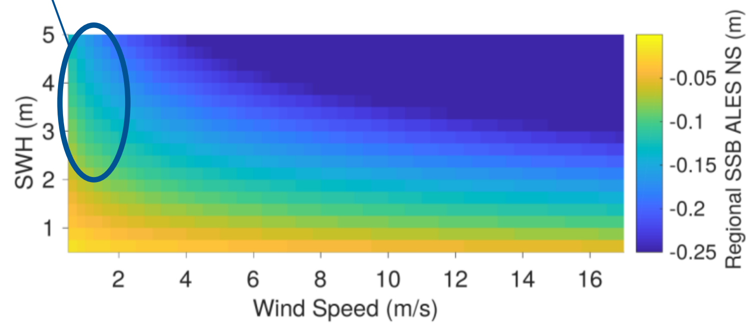
Comparison of regional SSB models

Regional differences are less evident, but present.
Different wind-wave regimes play a role

ALES Med

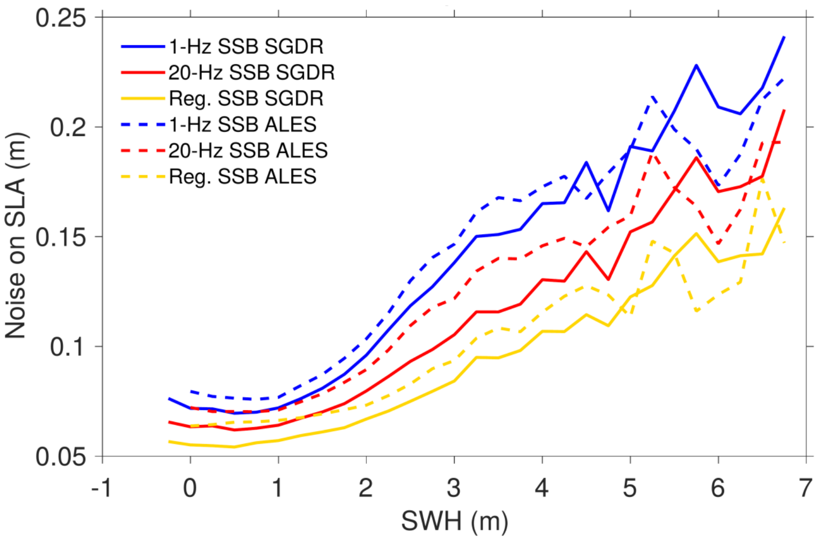


ALES North Sea

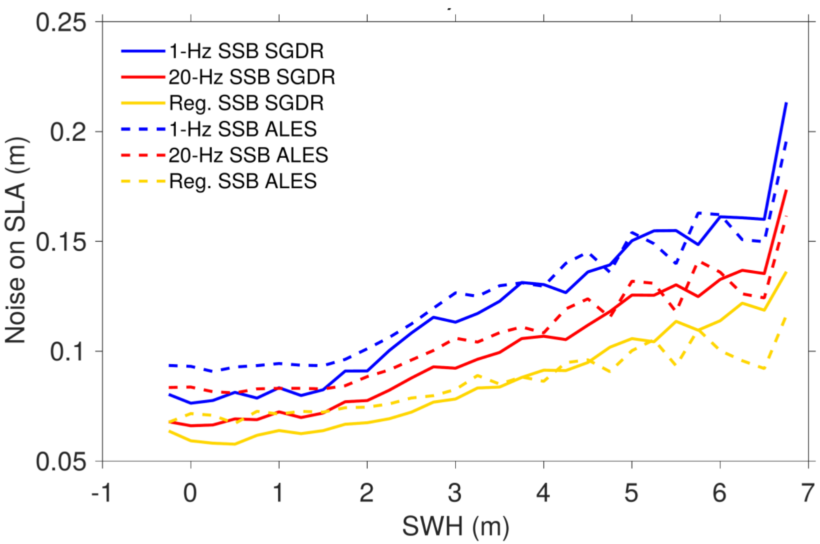


Noise Statistics

MEDITERRANEAN SEA



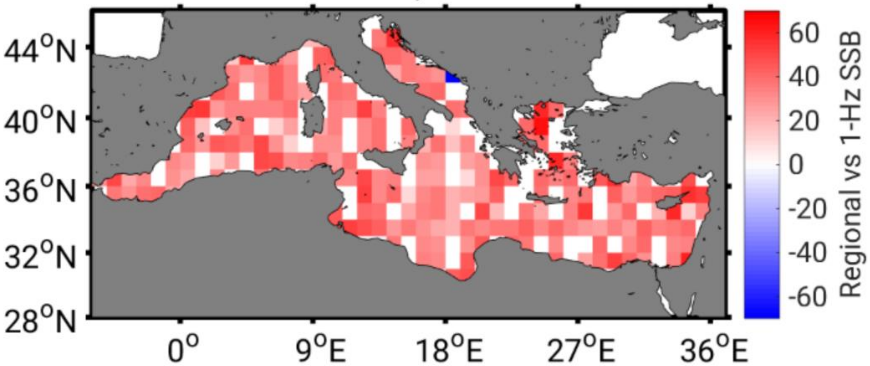
NORTH SEA



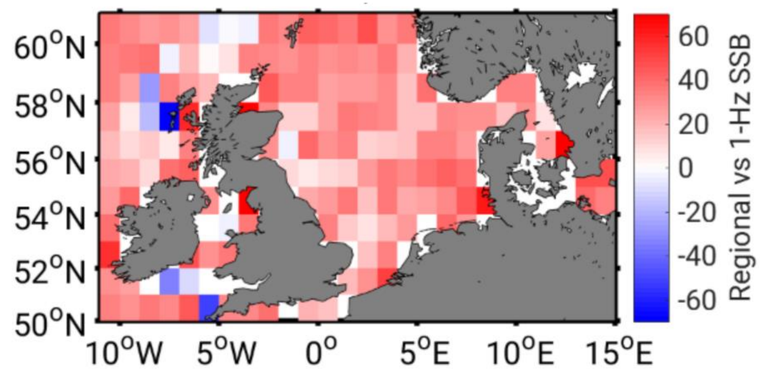
- Noise vs SWH is different for each region
- Going from low-rate to high-rate decreases systematically both low sea-state noise and slope of the noise curve, for any retracker
- The regional HF parametric SSB correction is superior to the global non-parametric SSB model, even if the latter is applied at HF

Metric of improvement: SLA Variance

MEDITERRANEAN SEA



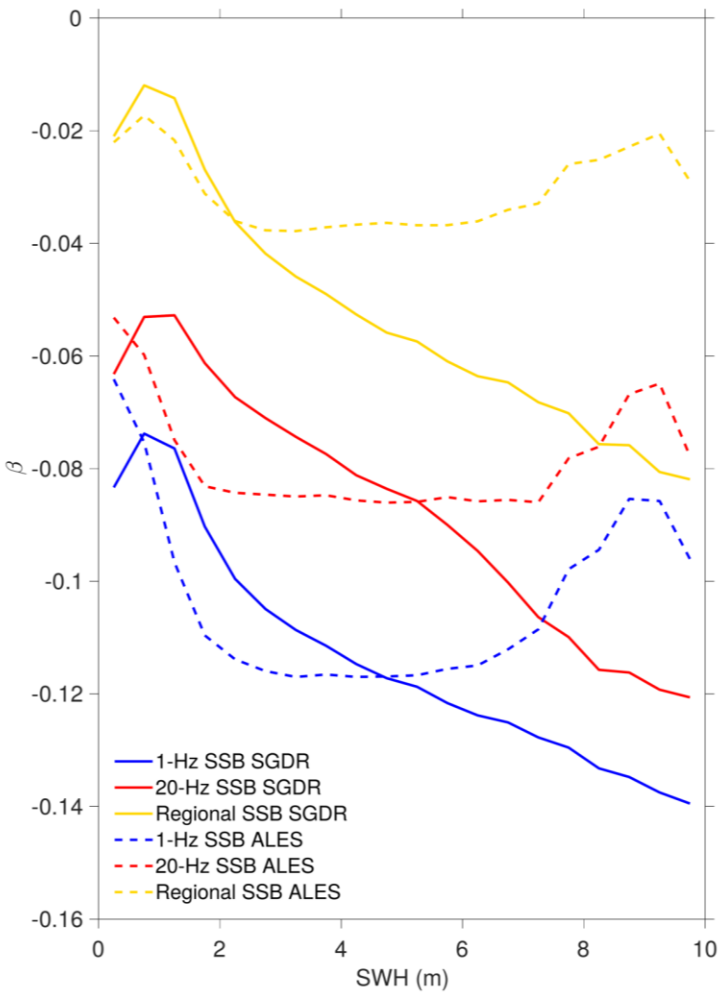
NORTH SEA



Dataset	20-Hz vs 1-Hz SSB [%]	Reg vs 20-Hz SSB [%]	Reg vs 1-Hz SSB [%]
SGDR Med	19.18	19.83	34.64
SGDR NS	17.31	15.01	29.93
ALES Med	14.05	18.77	29.34
ALES NS	12.21	16.67	25.81

NB: plots with SGDR dataset. With ALES dataset results are essentially the same (see spare slides)

Intra-1Hz regression slope SLA vs SWH



- Ideally, the 20 SLA and SWH estimations within each 1-Hz block are independent. In reality, correlated errors (different for each retracker) that influence the SSB are present (see talk by Quartly et al.)

- Correcting the SLA with 20-Hz SSB and with Reg SSB reduces the SLA-SWH correlation

- Drawback of this SSB strategy: we assume that HF retracker-related noise and LF physical SSB effect can be modelled together

Conclusions and future work

1) If you want to decrease the high-frequency noise of LRM altimetry by ~15%, apply the Sea State Bias model on 20-Hz data (alternative to „Zaron correction“, but focused on 20-Hz, not 1-Hz). Analysis presented in CAW2018 shows that global application reduces 1-Hz crossover variance by 30%, as in Zaron and DeCarvalho).

2) Going regional: a simple regional parametric sea state bias model is better than a global non-parametric one. Further improvements in precision (~30% HF noise)

3) Is this the final word? No, best strategy is: first eliminating intra-1Hz correlations between retracked parameter (different for each retracker), then re-estimate the SSB model at 1-Hz

4) Meanwhile, this is a solution that can be immediately applied to improve the precision

P.S. if you want to use a global sea level product (J1,J2) applying SSB at high-rate, download ALES data from https://openadb.dgfi.tum.de/en/data_access/

THANKS FOR YOUR ATTENTION

"The naturalness of a superior human being consists in the harmony between what is man made and what is made by Nature.„
Freely translated from Fernando Pessoa, *Livro do Desassossego*

Opportunities for Talents

The Deutsches Geodätisches Forschungsinstitut (German Geodetic Research Institute) of the Technical University of Munich (DGFI-TUM) is accepting applications for a

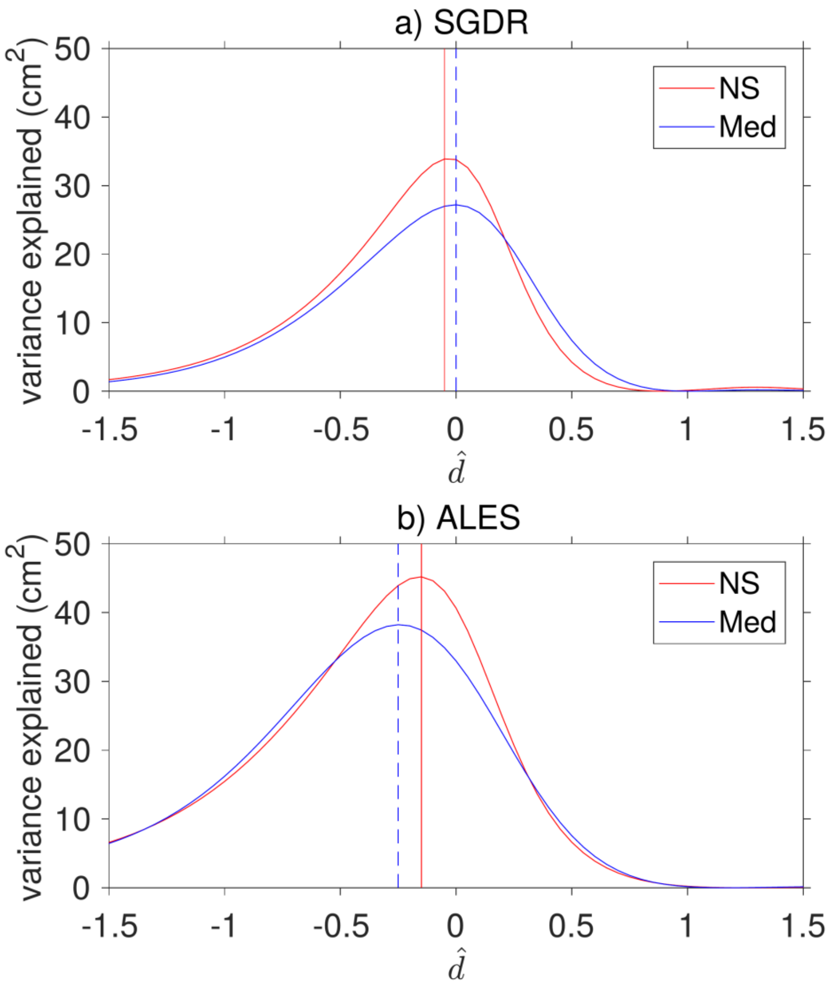
PhD student (m/f) in the research area Satellite Altimetry

DGFI-TUM is hiring
Contact us and/or get a flyer: marcello.passaro@tum.de
Poster Zone: CVL_009, TID_005, TID_004, IPM_005

P.S.: A paper on this work has been accepted in Remote Sensing of the Environment

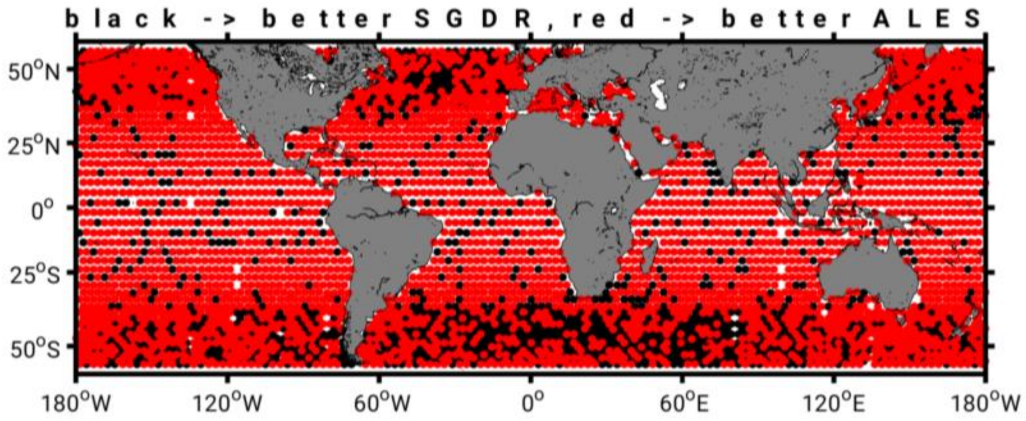
SPARE SLIDES

Methodology: regional model estimation



Crossover analysis – in space

Jason-1

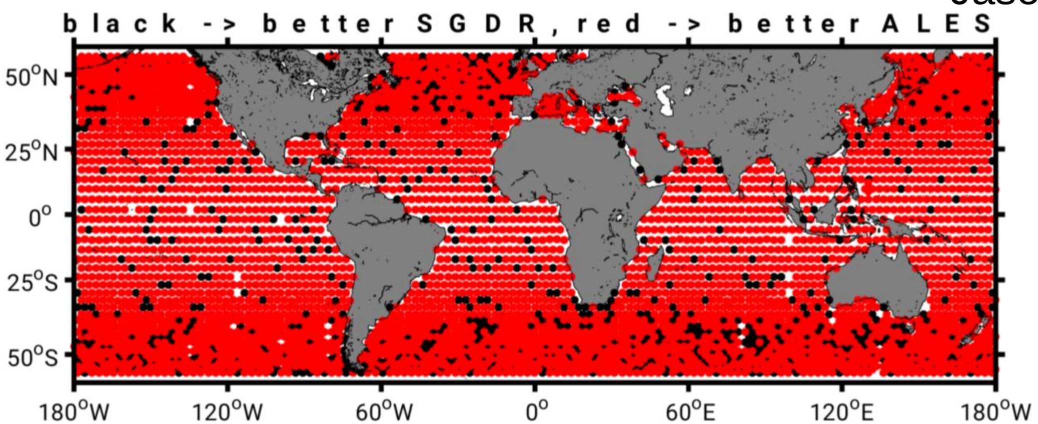


ALES is better in the 74% of the locations

Standard Deviation of the Crossovers

RED: std(ALES)<std(SGDR)

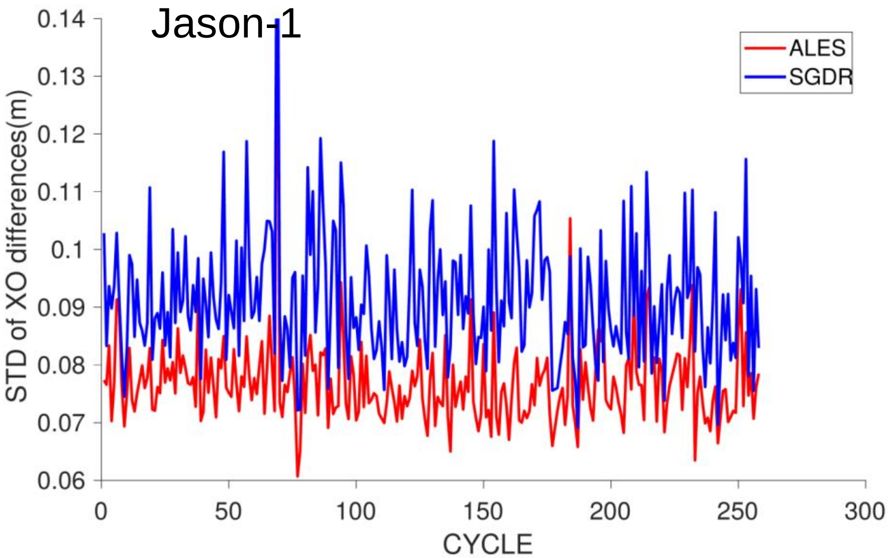
Jason-2



ALES is better in the 85% of the locations

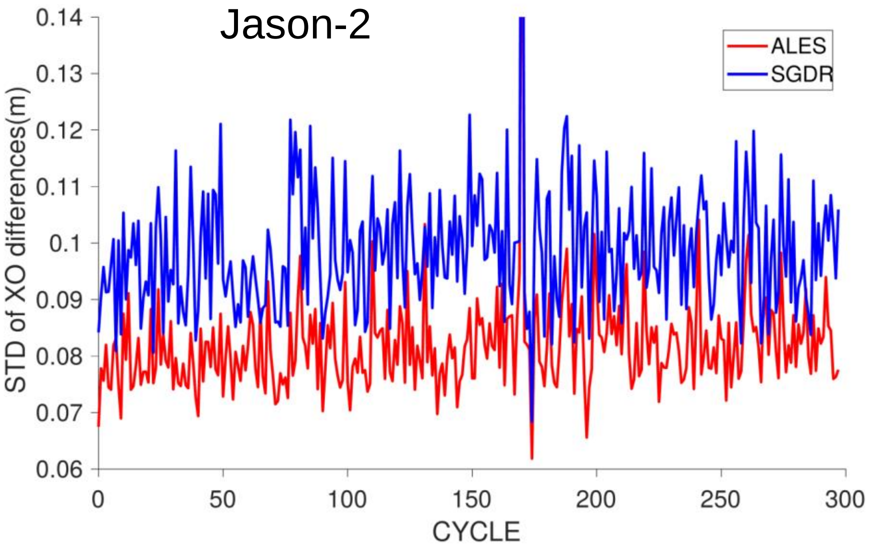
ALES IMPROVEMENT IS NOT RESTICTED TO THE COAST

Crossover analysis – in time



J1 Median improvement=1.3 cm

29% Variance Reduction



J2 Median improvement= 1.7 cm

30% Variance Reduction

Statistics

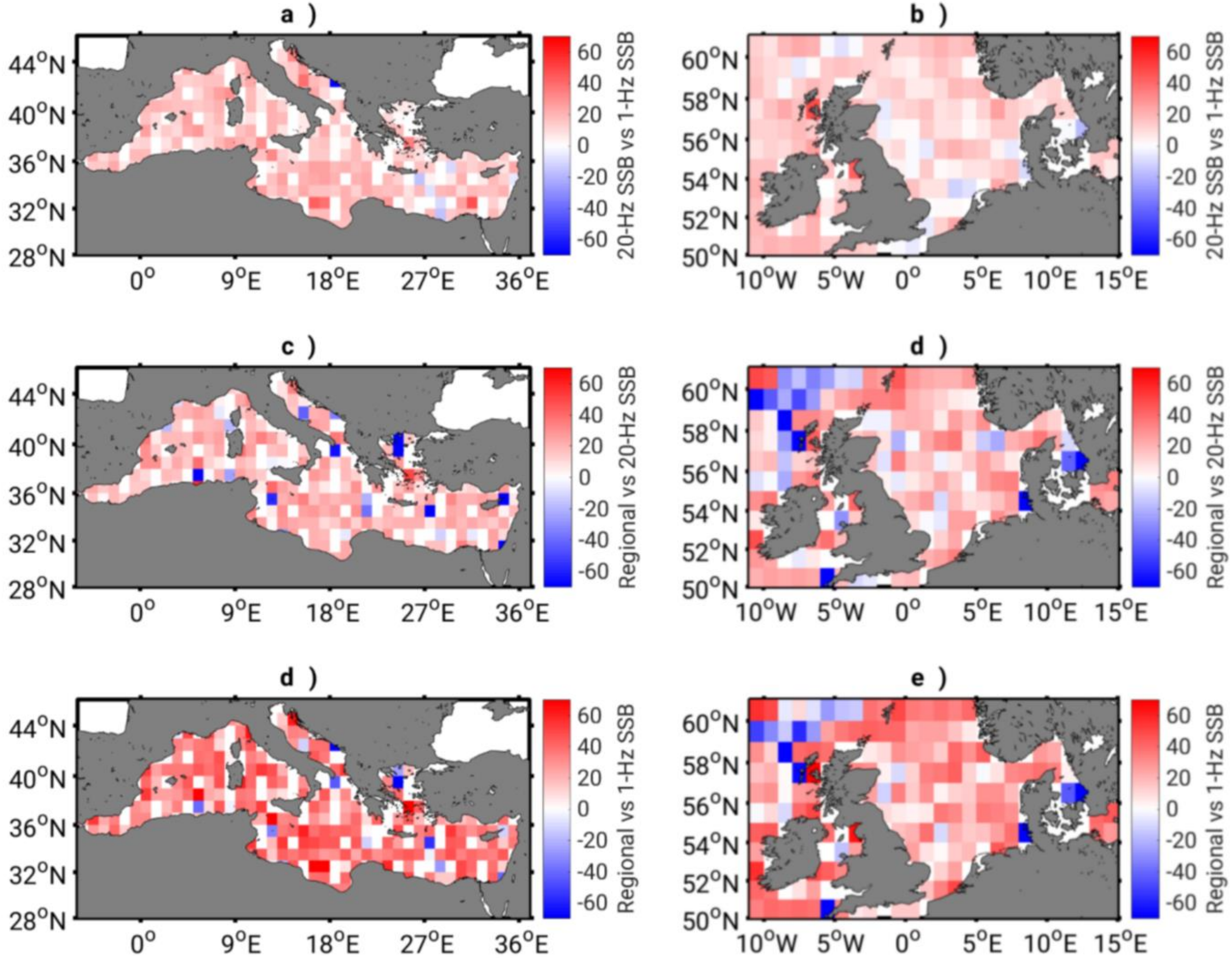
Jason-1 (without data gap)

	Between 20 and 3 km from the coast	In the global ocean
Std ALES	22.09 cm	7.99 cm
Std SGDR	25.41 cm	9.27 cm
Outliers XOs ALES*	6060	14679
Outliers XOs SGDR*	7248	20132

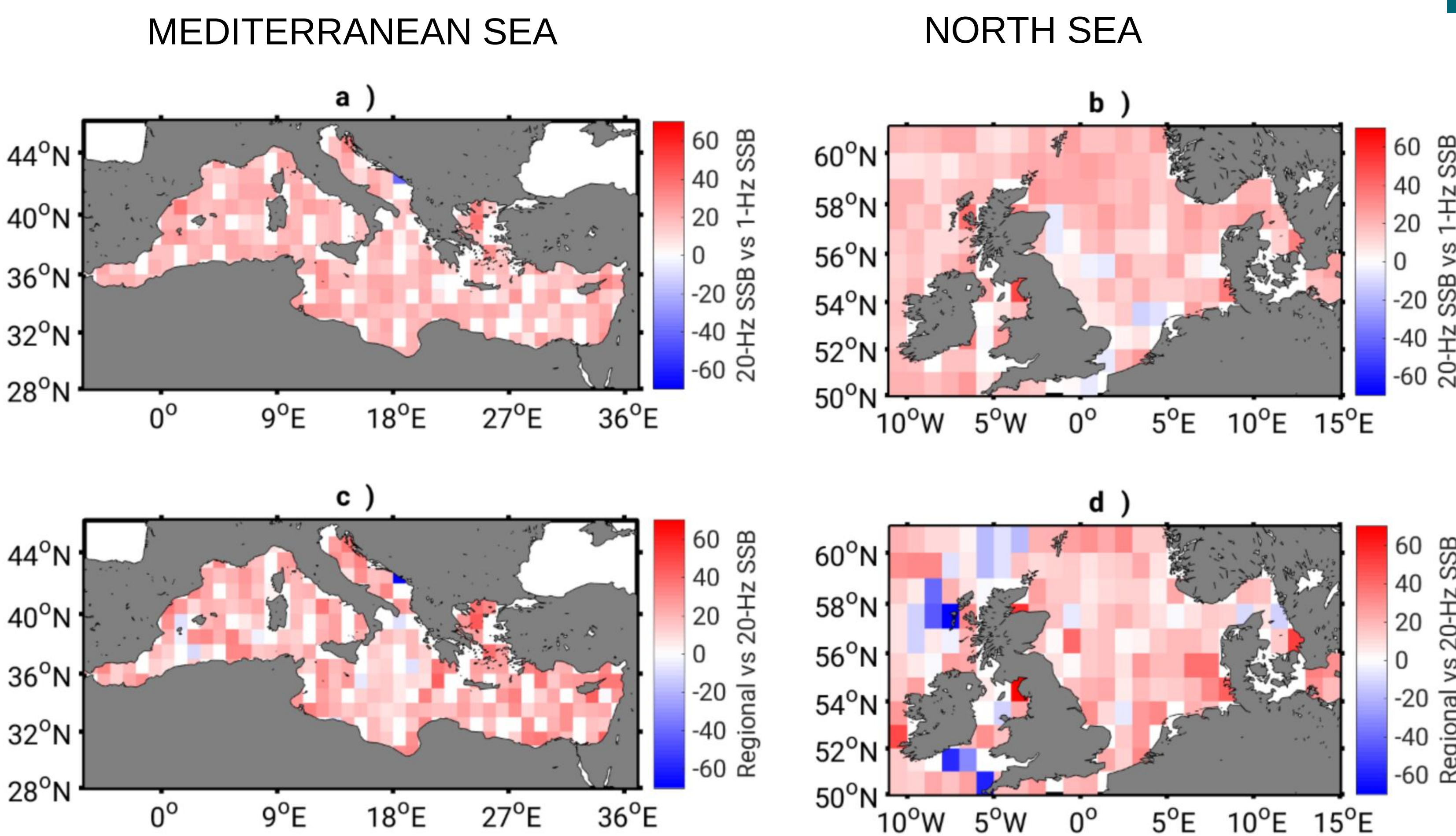
	Between 20 and 3 km from the coast	In the global ocean
Std ALES	28.66 cm	8.17 cm
Std SGDR	29.92 cm	9.86 cm
Outliers XOs ALES	6104	12773
Outliers XOs SGDR	8589	20245

Jason-2

Metric of improvement: SLA Variance for ALES

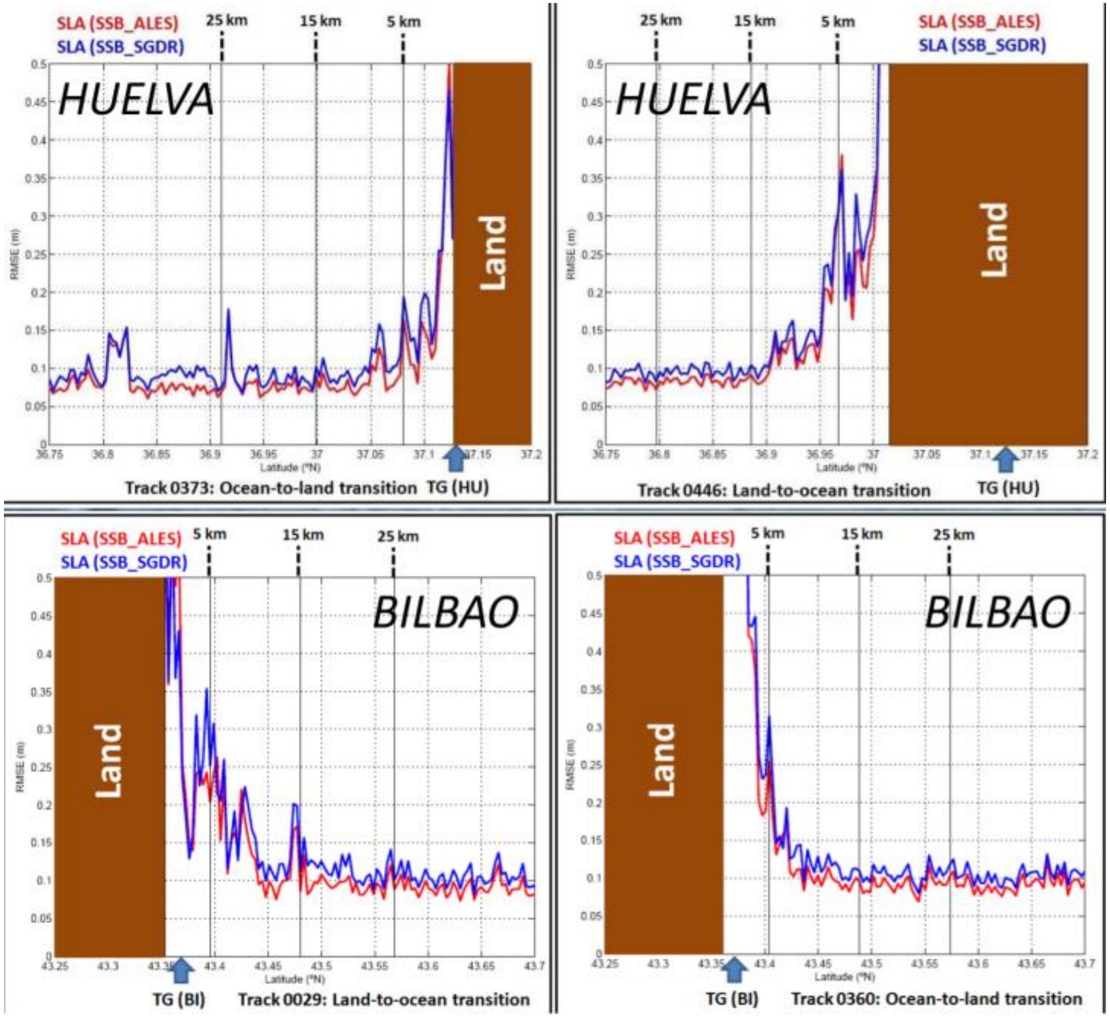


Metric of improvement: SLA Variance



NB: plots with SGDR dataset. With ALES dataset results are essentially the same (see spare slides)

Accuracy improvement: Tide Gauges



RMSE improvement using ALES HF SSB correction instead of standard 1-Hz SSB correction,
By Jesus Gomez-Enri

Metric of improvement: SLA Variance

Reducing Sea Level Anomaly variance at regional and global scale is the most common method to evaluate corrections: e.g. Wet Tropospheric Correction (Fernandes et al., 2015), Inverse Barometer Correction (Carrere et Lyard, 2003), Dynamic Atmosphere Correction (Pascual et al., 2008), and SSB itself (Tran et al., 2010).

We used the latest formulation by Pires et al. 2016, the „scaled SLA difference" which accounts for regional variability

Reference — Challenger

$$S = \left[\frac{(var(SLA1) - var(SLA2))}{var(SLA1)} \right] \times 100$$

Tip for the eyes in the next slide: if it's red, the challenger improves the reference